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Empowering the autonomy of children with cognitive and physical impairments by inertial head tracking

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Abstract

Physical and cognitive disabilities affect to motor skills and social integration. Cerebral palsy (CP) is the most common cause of motor disability in children. Motor skills of disabled infants are affected by different forms and different aids may be adapted to empower the infants' residual abilities. This work presents an interface based on inertial sensors that translates the movement of the head of the infant into movements of the cursor on the computer's screen. The interface can be considered as an input device for the computer (text editor, multimedia and playful applications) and assistive devices as well as a rehabilitation tool (biofeedback therapy).

Keywords:Inertial Sensors, Human Machine Interface, Cerebral Palsy, Assistive Technology, Rehabilitation.

1. Introduction. Cerebral Palsy and Technical Aids

The most frequently cited definition of cerebral palsy (CP) is 'CP is a disorder of posture and movement due to a defect or lesion in the immature brain'[1]. CP is the major physical disability affecting the functional development of children. The prevalence of CP is internationally 1.5 to 2.0 cases per 1000 births. Only in the United States 500,000 infants are affected by CP[2]. In Europe these figures are even higher[3]. Treatments for CP patients depend on the specific patient's pathology and range from physical therapy to medication and surgery. When distinguishing therapeutic approaches on their main emphasis, the following basic principles can be recognized: (1) emphasis on normalization of the quality of movement[4]; and (2) emphasis on functional activities, which focuses on the development of skills necessary for the performance of activities of daily living[1,5].

It is demonstrated that it is during early stages of development that fundamental abilities and skills are developed. Thus, it is crucial to give the child the possibility to be able to fully interact with the environment for an integral and ecological development. In this sense, it is recognized that new assistive technologies can help to improve a variety of functional skills otherwise limited by CP. Concretely, the interaction between the infant and the computer is considered as an interesting therapy. For instance, the use of video games increases the efficiency of information processing and concentration skills among learning6. The conventional interfaces for the computer such as mouse,

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Fig. 1. Trials with the inertial interface. A wireless communication based on Bluetooth is used to permit greater freedom of movement.

keyboard or joystick, are difficult to control for people with cognitive and physical impairments. Since these limitations, numerous research groups are working to find interfaces focused on restoring and augmenting the human capabilities. Some interfaces track the human movement by inertial sensors[7].

This work is focused on empowering the communication between the infant and his/her environment through an inertial interface. Although all areas of motor function are limited, generally the control arm and leg movements are more affected than head's movements. For this reason, the inertial interface presented tracks head's movements of the infant.

2. The inertial unit

The interface consists of a headset with a commercial helmet and an inertial unit (Fig.1). The inertial sensor integrates a three-axis gyroscope, accelerometer and magnetometer. A rate gyroscope measures angular velocity by measuring capacitance and it is based on the Coriolis force principle during angular rate. The accelerometer measures the gravity and the acceleration caused by motions (by Hookes law). The magnetometer measures the magnetic field of the earth. Each sensor has a 3D angular resolution of 0.05ºRMS, a static accuracy less than 1.0º and a dynamic accuracy of 2º RMS. Its dimensions are 35x25x12mm and its weight is 20 grams, which is a low mass system compared to other sensors used in the field. Micromachining techniques make possible the development of precision inertial sensors with a lower price and standard characteristics similar to those of integrated circuits, suitable for portable and wearable applications. The inertial unit has been developed by Technaid S.L. (www.technaid.com).

3. The algorithm for cursor control

3.1. Orientation of the inertial unit

The goal of the algorithm is to control the mouse on the screen of the computer. Therefore, it is necessary to translate the orientation of the inertial unit into displacements of the cursor on the screen. The first step is to estimate the orientation of the inertial unit. The algorithm designed fuses information from the magnetometer to estimate azimuth orientation and accelerometer to estimate the inclination respect to the gravity direction (elevation). The acceleration caused by motions is removed from gravity filtering the acceleration with a low pass filter (FIR 4^{th} order). The filter has been calculated according to a characterization of human motion where it is demonstrated that the frequency bandwidth in daily living activities is between 0 and 1Hz[8]. The gyroscope provides the direction of motion. The gyroscope presents a slow variable offset with the temperature. Some algorithms integrate gyroscope signal to estimate angular rotation. Therefore, the offset must be calculated and subtracted to eliminate a systematic bias caused by the integration of the offset. In our case, the angular velocity is used directly, so that errors caused by integration are not introduced. Only relative changes in gyroscope signal are measured to estimate the direction of motion. Once orientation is calculated, the angle rotation per axis can be calculated by (1).

$$\theta = acos\left([(u(t)\cdot u(t-1)] / [|u(t)|*|u(t-1)|] \right) \qquad (1)$$

Where θ is the angle between $u(t)$ and $u(t-1)$. Parameters such as angles rotations, angular velocities and accelerations will result interesting in order to identify involuntary movements as for example ballistic movements. If the angle is calculated for each axis, it is obtained a vector called φ which collects the rotations on X, Y and Z. According to Bortz[9], given the time history of the orientation of a rigid body, the angular velocity that generated that specify time history can be calculated by (2).

$$\omega = \varphi^{\bullet} - ((1-cos\varphi)/\varphi^2)\, \varphi X \varphi^{\bullet} + (1/\varphi^2)\, (1-(sin\varphi)/\varphi)\, \varphi X(\varphi X \varphi^{\bullet}) \qquad (2)$$

These concepts make a relatively simple algorithm respect to other complex filters as Kalman filter, with a very low computational cost that can be even integrated within a miniaturized sensor. These characteristics are optimal for wearable applications.

3.2. Translation from orientation to cursor displacement

The 3D vector φ contains the rotation angles in X, Y and Z directions corresponding to pitch, roll and yaw movements respectively. The movements used to displace the cursor on the screen are yaw and pitch. Yaw is translated to horizontal movement (azimuth) on the screen and pitch to the vertical movement (elevation). At the beginning, the range of the head's movement has to be calibrated for both directions (elevation and azimuth). Only three positions of calibration are necessary to define the horizontal and vertical range. Fig. 2a depicts a translation of 90º into a displacement of the cursor on the screen. It has been demonstrated that the accuracy on the positioning is less than 1º. Then, if the azimuth range is about 60º and the screen resolution is 1024 pixels, the error is less than 17 pixels. These conditions are even better if a projector is used instead of the screen of the computer, what not only improves the resolution but also other factors related to the infant such as attention and motivation.

4. Experiments

The first experiments were conducted in a CP center called ASPACE-Cantabria. They consisted of a moving cube (simulating the box of the sensor) on the screen according to the infant's head movement. The main goal was to identify the different groups of CP to focus the use of the interface. One of the most important findings was that the biofeedback improves the motor control of the head, because factors as attention and motivation are fundamental for the success of the task. Due to these facts among others, it was thought to relate the movement of the inertial headset with the movement of the cursor on the screen. Moreover, the computer applications (fig. 2b) developed intend to be adapted to these considerations. From the therapy point of view, these applications are aimed at problems of gross motor and fine-motor function (physical rehabilitation) and motor planning (cognitive rehabilitation). A virtual keyboard was chosen as a key application because allowing infants communicate through writing. A drawing application has been chosen because improving the learning of fine motor manipulation. Video games have been chosen too, because motivation is fundamental in all kinds of therapy and play as therapy is one good hook. Moreover, other training applications have been designed to classify the dexterity of the infants.

5. Discussion and future work

The inertial interface intends to be an alternative input device for empowering the communication for CP infants through the some activities as writing, drawing or playing with computer applications. The inertial interface results convenience for the infant because only a small and light inertial unit is placed on a commercial helmet. Moreover, only three positions of calibration are necessary reducing considerably the time of calibration respect to other similar interfaces. Both head's movement-cursor displacement and the performance of software applications have been developed and validated according to the laboratory experiments. Different educators and physiotherapists have confirmed that the proposed interface and applications allows new therapies so far difficult to propose. In a near future, new experiments will be carried out with the interface and the software applications proposed.

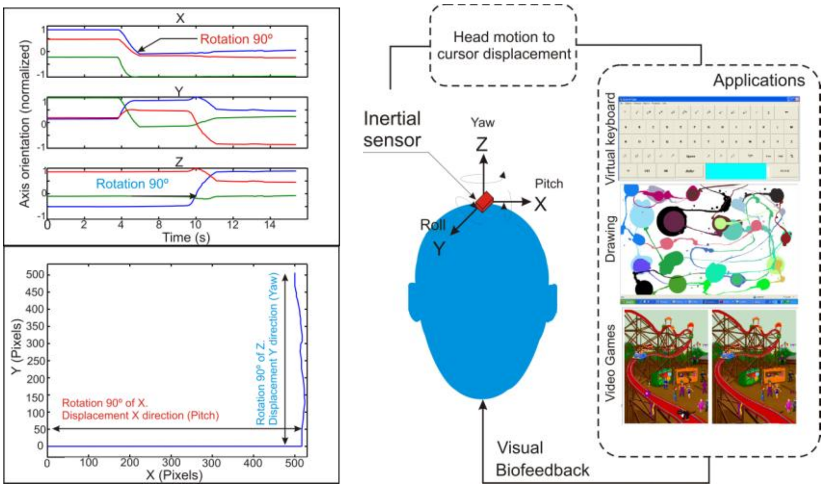

Fig. 2. a) Absolute orientation and cursor displacement. 1024 pixels correspond to 180º. Firstly, a gyro of 90º of axis X (around Z), implies a horizontal displacement to the middle of the screen, a gyro of 90º of axis Z (around X), implies the same vertical displacement b) Inertial unit and applications. Biofeedback improves motor skills of the infants.

The gross motor function will be evaluated with the interface (from goniometry) and the therapies will improve the daily living activities in the short and long term. Some standards of evaluation such as the gross motor function classification system (GMFCS) and/or Pediatric Evaluation of Disability Inventory will be applied.

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